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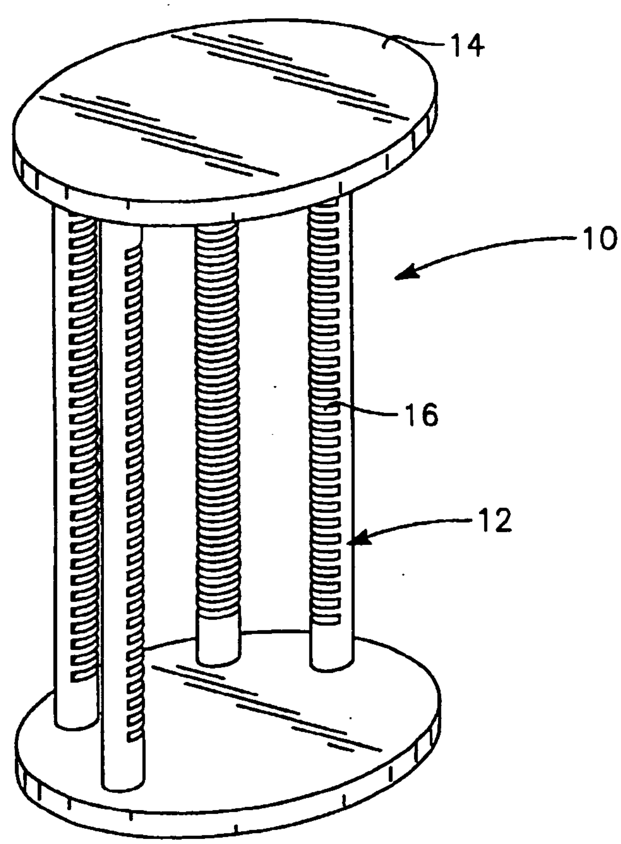
(54) Title: SILICON FIXTURES FOR WAFER PROCESSING AND METHOD OF FABRICATION

(57) Abstract

A silicon tower for removably supporting a plurality of silicon wafers during thermal processing. A preferred embodiment of the tower includes four legs secured on their ends to two bases. A plurality of slots are cut in the legs allowing slidable insertion of the wafers and support for them. The legs preferably have a rounded wedge shape with a curved front surface of small radius cut with the slots and a curved back surface of a substantially larger radius. Preferably, the legs are machined from a round bar of virgin polysilicon. The bases may be either virgin poly or monocrystalline silicon. Various attachment methods are available for securing the legs to the bases, including fusing legs to the bases with the application of energy.



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SILICON FIXTURES FOR WAFER PROCESSING AND METHOD OF FABRICATION

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates generally to fixtures used for supporting wafers in the fabrication of semiconductor integrated circuits. In particular, the invention relates to silicon fixtures for supporting wafers.

2. Technical Background

In the evolution of commercial fabrication of silicon wafers, larger and larger wafers are being processed in larger and larger batches at the same time that feature sizes are decreasing to 0.18μm and less. Such processing has imposed increasingly more demanding requirements of the performance of processing equipment, as well as that of the wafer handling and carrying mechanisms needed to move, transport, and retain the wafers during processing. These requirements include temperature uniformity and contamination, whether of impurities or particles.

In many chemical and thermal processing operations, it is often necessary to hold the wafers in precise positions during various processing steps, and in particular during annealing, dopant diffusion, or chemical vapor deposition simultaneously performed on many wafers. Relatively large and complex structures such as "boats" or "towers" are typically employed to that end. One example of such a structure is described in U.S. Patent No. 5,492,229 to Tanaka et al. Tanaka et al. describe a vertical boat for holding a plurality of semiconductor wafers. The boat includes two end members and a plurality of support members. In one embodiment, the support members are formed from pipe members cut vertically to provide a long plate member having a cross section of a quarter-circular arc. In another embodiment, the support members are formed from pipe members cut vertically to provide a long plate member having a cross section of a semicircular arc. Tanaka et al. list potential materials for

their boats as silica glass, silicon carbide, carbon, monocrystalline silicon, polycrystalline silicon, and silicon carbide impregnated with silicon. The various components are to be welded together if made from silica glass; otherwise, "they may be assembled in a predetermined manner."

U.S. Patent No. 5,534,074 to Koons is also directed to a vertical boat for holding semiconductor wafers. The boat includes a plurality of rods having slots cut along their lengths. The configuration of the slots is intended to reduce shadowing on wafers placed within the boat during processing. The rods are cylindrical, and are specified as being made from fused quartz, although "any known material suitable for holding wafers may be used."

U.S. Patent No. 4,872,554 to Quernemoen shows a reinforced carrier for silicon wafers and the like. The carrier includes side components consisting of tubular rails with teeth projecting therefrom for supporting the wafers with fixed spacing. The rails are made from plastic, and may include rigid inserts for stiffening purposes. The teeth can be integrally molded with, or fused to, the rails.

U.S. Patent No. 5,752,609 to Kato et al. is directed to a wafer boat including a plurality of rods arranged to support ring members. A plurality of wafer supporting pieces are associated with the ring members, and include angular projections for contacting the wafers. Kato et al. also describe a wafer boat having a plurality of cylindrical quartz rods with wafer support recesses formed therein.

The theoretical advantages provided by pure silicon structures are well known. Conventional towers and boats are typically made from quartz or silicon carbide, which introduce contamination and become unstable at higher temperatures. By fabricating wafer holding structures from the same material as the wafers themselves, that is, silicon, the possibility of contamination and deformation is minimized. The silicon structure would react to processing temperatures, conditions, and chemistry in exactly the same way that the wafers would, thus greatly enhancing the overall effective useful life of the structure.

Unfortunately, standard assembly of silicon structures in a "predetermined manner" as set forth by Tanaka et al. is one of the reasons that pure silicon has not gained wide acceptance as a material for structures such as boats and towers. The difficulties of working with monocrystalline silicon, polycrystalline silicon, and virgin

polycrystalline have led to the development of structures such as that shown in Tanaka et al., wherein, when considering monocrystalline silicon as the material of choice, the connections between the support members and the end members are not described at all, and the only specifically described method of fabricating support structures involves cutting extruded tubular members. Such support structures are inherently less stable than those made from more traditional and easily-worked materials such as quartz or silicon carbide.

Similarly, the patents to Koons, Quernemoen, and Kato et al. fail to address the specific problems of providing a strong, reliable wafer support structure that reduces shadowing and contamination. The projections and slots described in these patents, while effective to some extent, are either not suited for fabrication from materials such as silicon, or require a relatively large cross-sectional area to provide stable and precise wafer support.

Silicon is perceived as being extremely fragile and difficult to fuse. Due to these perceptions, known silicon structures are widely believed to be delicate at best, and unreliably flimsy at worst. Consequently, they have failed to receive broad commercial acceptance.

Furthermore, due to the crystal structure of monocrystalline silicon, blanks extruded from crystalline silicon have a distinct "grain" running generally longitudinally through the blank. Silicon blanks are usually cut laterally, across the grain, using a scroll saw. Unfortunately, when used to make longitudinal cuts, conventional cutting techniques tend to split silicon blanks along the grain, thus ruining the blank.

It can be seen that the need exists for a method of fabricating monocrystalline and polycrystalline silicon structural members for use in the manufacture of semiconductor wafers and the like that will eliminate the disadvantages of known silicon structures while retaining the advantages of silicon as a structural material.

Czochralski (CZ) monocrystalline silicon is the type used as wafers in semiconductor integrated circuits and consists of essentially a single crystal of silicon of horizontal dimensions extending to 200 and 300mm drawn as large ingot from a silicon melt. Czochalski polycrystalline silicon, often referred to as semi-single crystal silicon, has virtually the same local structure as monocrystalline silicon but is

composed of separate crystallites. The crystallites have sizes of the order of 1mm to above 100mm and are separated by grain boundaries. Such CZ polysilicon is believed to be the conventionally presented polysilicon in the context of structural members. Whether CZ silicon is grown in monocrystalline or polycrystalline form depends in large part upon its drawing rate. CZ silicon can be grown with heavy metal impurities of 1 part per million (ppm), but carbon and nitrogen may be present in concentrations between 1 and 7ppm, while oxygen is present in concentrations between 10 and 25ppm. The crystallites typically have very similar orientations with respect to each other. Further, polysilicon is often grown as thin layers in silicon integrated circuits by chemical vapor deposition, but such films are not directly applicable to the invention.

Virgin polysilicon, hereinafter virgin poly, is a special type of polysilicon extensively manufactured for use in the semiconductor industry. Virgin poly is formed into relatively large ingots (diameters of up to approximately 15cm) by the thermal chemical vapor deposition (CVD) using various silanes as the precursors which condense on a heated seed rod. Such precursors include SiH_4, $SiClH_3$, $SiCl_2H_2$, $SiCl_3H$, and $SiCl_4$. Of these, $SiHCl_3H$ is the most commonly used commercially, but monosilane (SiH_4) is sometimes used based on its historic usage in float-zone deposition. Virgin poly is grown to very high levels of purity with impurity concentrations of $10^{-12}cm^{-3}$ or less. The generally expressed criterion is that it contains on the order of 1ppt (1 part per trillion, 1×10^{-12}, impurities of all possible contaminants including oxygen). Even with some variations, virgin poly has an impurity level of less than 10ppt. This contrast with Czochralski-grown polysilicon having various impurities of at least 1ppm for heavy metals and up to 25ppm and greater for dissolved gases. Virgin poly is commercially grown to have high internal stress so that it easily shatters. Semiconductor silicon wafers are usually grown by the Czochralski method in which the polysilicon is shattered and then melted together with perhaps intentionally introduced dopant materials at temperatures in the neighborhood of just above 1416°C, the melting point of silicon at ambient pressure. A single crystal is nucleated on a small seed crystal placed at the surface of the melt, and the growing single crystal ingot is very slowly pulled from the melt.

Whether Czochralski-grown silicon forms in the monocrystalline or

polycrystalline state depends in large part on its pulling rate, and the crystallites tend to be large though of random size. On the other hand, virgin poly nucleates from a hot seed rod and thus tends to form crystalline arms radiating from the rod.

As far as is known, virgin poly has not been used in silicon fixtures for supporting wafers in semiconductor processing.

It can thus be seen that the need exists for a strong, reliable support member for wafer processing fixtures that will reduce shadowing and contamination while providing stable and precise wafer support.

SUMMARY OF THE INVENTION

The invention includes a silicon wafer processing fixture. The fixture includes a generally elongate silicon support member having an attachment element extending outwardly from a terminal end thereof. The fixture also includes a generally planar silicon base. The base includes an attachment element receiving portion having the attachment element of the support member fixedly secured therein.

In a primary embodiment, at least one part of the fixture is composed of virgin polysilicon. In one more specific embodiment, the elongate member is machined from virgin polysilicon and an integral base is monocrystalline silicon. In another embodiment, the base is composed of several parts, and the parts and the elongate member are all formed from virgin polysilicon.

A method for fabricating elongate structural members from a unitary blank of crystalline material is provided. The blank has a predetermined length, width, and depth. A first substantially planar cut is made in the blank, the cut extending substantially along the entire length of the blank and substantially less than the entire width of the blank. At least one additional cut is made in the blank, the at least one additional cut extending in the same plane as the first cut, to cut the blank into two pieces.

The step of making at least one additional cut can include making a plurality of additional cuts, in one embodiment at least three additional cuts. The cuts can be made using a rotary saw with a blade having diamond-coated cutting surfaces. The saw can be operated with the blade rotating at between 50 rpm and 50,000 rpm, preferably at approximately 4,000 rpm.

The blank of crystalline material can be provided as a unitary blank of silicon material. The method of the present invention can be practiced using monocrystalline silicon material or polycrystalline silicon material.

In an embodiment, the blank can be provided as a generally cylindrical blank or ingot. The step of making a first substantially planar cut and the step of making at least one additional cut can be repeated on each of the two pieces to make four pieces from the original cylinder, and subsequently repeated to yield eight pieces from the original cylinder, each of the eight pieces having a substantially wedge-shaped cross-section.

A method of securing a first silicon member to a second silicon member to form at least a part of a silicon wafer processing fixture is disclosed, as is the silicon wafer processing fixture itself. The method includes the step of providing a first silicon member with an outwardly-extending attachment element. A second silicon member is provided, with an attachment element receiving portion adapted to at least partially enclose the attachment member. The attachment element is then fixedly secured within the attachment element receiving portion.

A method of fabricating support members for wafer processing fixtures is disclosed. In the first step of the method, an elongate support member basic form is provided. The basic form has a substantially wedge-shaped cross-section and angular edges. Next, the edges of the support member basic form are machined to replace the angular edges with substantially arcuate edges. A plurality of wafer-retaining slots are cut along one side of the support member basic form.

The support member basic form can include a front surface and a rear surface, with at least one angular edge occurring on each of the surfaces. The step of machining the edges of the support member basic form can be performed as machining the edges on the respective surfaces to radii of between 0.25" (6.3mm) and 5.25" (133.3mm). In an embodiment, the at least one angular edge occurring on the rear surface can be machined to a radius of approximately 1.5" (38mm), and the at least one angular edge occurring on the front surface can be machined to a radius of approximately 0.35" (8.9mm). Advantageously, no other corner of the support member has a radius less than that of the front surface.

At least one attachment structure can be provided on at least one terminal end

of the support member basic form. The attachment member is adapted and constructed to facilitate attachment of the support member to a generally planar base member. In an embodiment, the attachment structure can be provided as a pair of cylindrical pegs, each of which extends from a respective terminal end of the support member basic form.

The elongate support member basic form can be fabricated from an inert crystalline material, such as polycrystalline silicon or monocrystalline silicon.

The step of cutting a plurality of wafer-retaining slots along one side of the support member basic form can be performed such that a plurality of cuts are made substantially perpendicular to the longitudinal axis of the support member basic form. The cuts can extend a suitable distance through the depth of the support member basic form, and can be made with a rotary saw with a blade having diamond-coated cutting surfaces. The wafer-retaining slots can be formed perpendicular to the front surface of the support member basic form.

A support member for wafer processing fixtures is also disclosed. The support member can include an elongate body portion having a pair of opposite terminal ends, an arcuate front surface with a first radius of curvature, and an arcuate rear surface with a second radius of curvature. The first radius of curvature can be substantially smaller than the second radius of curvature. A plurality of mutually parallel wafer-retaining slots are formed in the front surface of the body portion.

In an embodiment, a pair of attachment structures can extend from respective terminal ends of the support member. The attachment element can be generally cylindrical, with the attachment element receiving portion being formed as a cylindrical bore having a diameter and length corresponding to those of the attachment element. However, other shapes, such as a blade, are possible. The first and second silicon members including the attachment member can be formed from monocrystalline silicon, polycrystalline silicon, or virgin polysilicon.

According to one method, embodiment, the step of fixedly securing the attachment element can be accomplished by providing a first transverse bore in the attachment element and a second transverse bore in the attachment element receiving portion. The first and second transverse bores are coaxial with one another, and adapted to receive a locating pin. Once the first and second bores are coaxially

aligned with one another, the locating pin is secured in the first and second transverse bores. The pin can be provided with a length slightly greater than the combined length of the first and second bores, in which instance the pin can be secured in the following manner. First, the locating pin is inserted in the aligned bores such that a portion of the locating pin extends outwardly from an outer limit of the first and second bores. Next, the extending portion of the locating pin is machined off flush with the outer limit of the first and second bores. Alternatively, the locating pin can be provided with an outer diameter substantially equal to an inner diameter of the first and second bores, in which instance the pin can be secured in the following manner. First, the locating pin is cryogenically frozen, causing the locating pin to contract. Next, the locating pin is inserted in the aligned bores while maintaining the bores at ambient or higher temperature. Then, the locating pin is caused to expand by allowing the locating pin to return to ambient temperature.

In an alternative securing step, energy can be applied to at least one of the attachment element and the attachment element receiving portion to fuse the attachment element to the attachment element receiving portion. In an embodiment, the attachment element receiving portion of the second silicon member is provided with an access bore. Laser energy is applied through the access bore to form a tack weld between the attachment element and the attachment element receiving portion. Alternatively, the attachment element and the attachment element retaining portion can be substantially coextensive. Laser energy can be applied to an area adjacent to both the attachment element and the attachment element receiving portion.

In yet another embodiment, the first silicon member is provided with a peripheral ridge at its terminal end. The second silicon member is provided with a peripheral trench at its terminal edge. Laser energy is applied to cause the peripheral ridge of the first silicon member to melt into the peripheral trench of the second silicon member. Laser energy is applied to heat the ridge to a temperature the melting point of silicon 1416°C, and preferably of approximately 1450°C for approximately 3 minutes, or until the silicon melt has filled the peripheral trench.

In still another embodiment, the step of fixedly securing the attachment element within the attachment element receiving portion includes the step of applying a high-bond, non-contaminating adhesive between the attachment element and the

attachment element receiving portion.The attachment element can be generally cylindrical, with the attachment element receiving portion being formed as a cylindrical bore having a diameter and length corresponding to those of the attachment element. The first and second silicon members can be formed from monocrystalline silicon, polycrystalline silicon, or virgin polysilicon.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 illustrates an orthographic view of a silicon wafer processing fixture incorporating the principles of the present invention.

FIGURE 2 illustrates a blank for use with the method of the present invention.

FIGURE 3 illustrates a flow chart setting forth steps included in an embodiment of the present invention.

FIGURES 4 and 6 are side cross-sectional views of a blank during the cutting process.

FIGURES 5 and 7 are axial cross-sectional view of the blank corresponding to FIGURES 4 and 6.

FIGURES 8 through 10 illustrate various steps included in the method of the present invention.

FIGURE 11 illustrates a support member basic form for use with the method of the present invention.

FIGURE 12 is an end elevational view of a support member basic form at a first stage of the manufacturing process.

FIGURE 13 is a side elevational view of a support member basic form at a subsequent stage of the manufacturing process.

FIGURE 14 is an orthographic view of a first embodiment of a combination of a a base.

FIGURE 15 illustrates a side elevational view of a support member basic form at another stage of the manufacturing process.

FIGURE 16 is an orthographic view of a second embodiment of a combination of a leg and a base.

FIGURES 17 through 23 illustrate sectional views showing techniques for securing the components of silicon wafer processing fixtures.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A silicon wafer processing fixture 10 is shown in FIG. 1. The silicon wafer processing fixture 10 includes a plurality of generally elongate support members 12, hereinafter called legs, secured between a pair of generally planar base members 14, hereinafter called bases. A plurality of slots 16 are cut into each of the legs 12, typically with equal spacings, and are used to support a plurality of wafers in the assembled tower 10. The tower is typically semi-permanently placed in a semiconducting processing reactor configured for one of a number of different processes. Multiple wafers are placed into the tower 10 and then simultaneously processed. The process may involve medium temperatures in the range of 400 to 700°C or high temperatures in the range of 1000 to 1380°C depending in part on whether chemical vapor deposition, an anneal, or a thermal diffusion is being performed.

The illustrated tower 10 has four legs 12 although three legs 12 and even two legs 12 or possibly one leg 12 would suffice. Most typically, the multiple legs are attached to the bases 14 around slightly more than 180° of the periphery of the bases 14 so that the legs 12 dependably support the wafers but the wafer can be linearly inserted through the slots 16 by an automated robot supporting the wafer on a paddle traveling transversely to the axis of the tower 10.

The legs 12 and bases 14 can be fabricated from an inert crystalline material, such as monocrystalline or polycrystalline silicon, and can be fabricated in any suitable manner. Preferably, the legs 12 are formed of virgin poly because of its reduced impurity levels since the legs 12 are in direct contact with the wafer. Also, the legs 12 in many applications need to be relatively long, and long virgin poly is readily available. However, the bases 14 are conveniently formed of single crystal silicon. The bases 14, which are conveniently formed in generally circular shapes, need to have diameters larger than the wafers being processed. At the present time, most wafers have 200mm diameters, but 300mm wafers are being introduced into production. Ingots of virgin poly of greater than 300mm or even 200mm are not readily available while extra large CZ crystalline ingots are available for speciality applications.

The fabrication of the legs is divided into two principal steps: (1) the

formation of a basic form having a wedge shape; and (2) the machining of the basic form into a leg of novel cross-section.

The basic form is machined from a cylindrical blank 20 shown in FIG. 2. The blank 20 is generally cylindrical, with a length L and a diameter D. However, it is contemplated that the present invention is applicable to any suitable blank having virtually any configuration.

The blank 20 may be fabricated from a crystalline material, such as monocrystalline or polycrystalline silicon, but at the present time virgin poly blanks are preferred. Silicon blanks are widely available commercially. One supplier of suitable silicon blanks is SILICON CRYSTALS INC. Blanks can be manufactured in any size, but are typically between 4" (10cm) and 80" (200 cm) long, with a diameter between 0.75" (2cm) and 36" (91cm).

As shown generally in FIG. 3, the method according to one aspect of the present invention uses a series of incremental cuts along the longitudinal axis of the blank 10 to cut the blank into pieces. At step 22, a first substantially planar cut C_1 is made in the blank 20. As illustrated in the side cross-sectional view of FIG. 4 and the axial cross-sectional view of FIG. 5, the first cut C_1 extends substantially along the entire length L of the blank 20, and substantially less than the entire width (here the diameter D) of the blank 20.

In step 24 of FIG. 2, an additional cut C_2 is made in the blank 20. As illustrated in the side cross-sectional view of FIG. 6 and the axial cross-sectional view of FIG. 7, the cut C2 extends in the same plane as the first cut C1.

If the blank 20 is of relatively small diameter, two cuts may suffice to cut the blank into halves, H_1 and H_2, as illustrated in FIG. 5. Otherwise, (N-2) additional cuts C_3 through C_N may be required, as indicated at step 16 of FIG. 3 to completely separate the two halves H_1, H_2 of FIG. 8. For a typical blank having a diameter of 3" (76mm), it has been found that 3 cuts achieve good results. However, high-pressure fluid cutting has been shown effective at cutting through the entire blank 20 in a single step. Furthermore, single-step cutting with a diamond blade may be effective if surface finish may be compromised.

Cutting of the blank 20 may be accomplished through any suitable technique. It is presently contemplated that the described cuts can be effectively accomplished by

using a rotary saw, such as a model M4K34F21G manufactured by MK. The saw can be equipped with a diamond-tipped blade, for example, part number 10125D22 or 10125D100, manufactured by National Diamond Lab. During cutting of the blank, it is contemplated that the saw can be operated at speeds ranging from 50 rpm to 50,000 rpm. It has been discovered that a speed of approximately 4,000 rpm is particularly effective. It is to be understood that the use of a rotary saw, while effective, is merely illustrative. It is contemplated that alternative cutting apparatus could be employed to achieve acceptable results. Examples of such apparatus include, but are not limited to, saws using non-diamond blades, lasers, wire saws, abrasive saws, reciprocating saws, and abrasive fluid cutting devices.

Frequently, the fabrication of structural support members may be enhanced by providing pieces smaller than the half-blanks H_1, H_2 shown in FIG. 8. In such instances, in step 26 of FIG. 3, the incremental cutting steps described can be repeated on each of the two pieces to make four pieces Q_1 through Q_4 from the original blank 20, as shown in FIG. 9, or the eight pieces E_1 through E_8, as shown in FIG. 10. The resultant basic leg form 30 illustrated orthographically in FIG. 11 has an apex angle of 45°. The depth of the cuts is reduced in step 26 so the value of N may be reduced.

The procedure described above may be modified as required to produce a solid segment have an apical angle of selected value less than 90°, but an angle of 45° or less is preferred to minimize shadowing.

The basic leg form 30 shown in FIG. 11 has a substantially wedge-shaped cross section. The basic leg form 30 has a front surface 32 with an angular edge 34 at the front of the wedge. The basic leg form 30 has an arc-shaped rear surface 36 with a pair of angular edges 38 at the back of the wedge and two planar side faces inclined with respect to each other.

The steps by which the support member basic form 30 is fabricated into a finished support member are illustrated in FIGS. 12 through 14. As shown in FIG. 12, the first step involves machining the front and rear surfaces of the basic leg form 30 (here shown in broken line) to eliminate the angular edges 34, 38 to thereby form a rounded trapezoidal piece 40. The surfaces can be machined to radii of between 0.25" (6mm) and 5.25"(133mm). In the illustrated example, the front surface of the trapezoidal piece 40 10 is machined to a radius of approximately 0.35"(9mm), and the

rear surface is machined to a greater radius, approximately 1.5" (38mm). Preferred ratios of the radii of the rear and front surfaces are at least 3 more preferably at least 4. An advantage of the significantly different ratios is that the wafer-supporting slots are cut on the side of the smaller radius so that less shadowing of the wafer occurs during processing while the larger radius distant from the wafer provides mechanical rigidity.

The rounded wedge shape of FIG. 12 has two further advantages. First, it minimizes the material lost during machining. Secondly, there is no feature more acute (of smaller radius) than the front surface into which are cut the slots. As a result, there is no acute corner, which tends to flake off accumulated deposits and thus increase the particle count. That is, the rounded shape increases adhesion for any film deposited on the fixture during wafer processing.

Alternative embodiments include a rounded wedge shape at the front and a rounded rectangular shape at the back of the leg with all the surfaces being joined with curved portions having a radius the same or larger than that of the front corner into which the slots are cut.

The radii shown in FIG. 12 can be machined using any suitable machine tool. One example of such a machine tool is a plated diamond router or a resin bond diamond wheel with a water swivel, manufactured by National Diamond Lab. It has been found that such a machine tool achieves effective results when used in conjunction with a bit such as a custom resin bond diamond wheel available from National Diamond Lab.

Once the basic leg 40 has been machined, the plurality of wafer-retaining slots 16 are formed, as shown in FIG. 13. The slots 16 are cut along one side, here the front surface, of the basic leg form 40 to form a slotted leg 42. The slots 16 are mutually parallel, and substantially perpendicular to a longitudinal axis A of the basic leg form 36 of FIG. 1. The slots 16 extend along a substantial portion of the length L but avoid the end lengths E. The slots 16 can extend either more or less than halfway through the depth D of the support member basic form, as the specific application dictates. Although the illustrated slots 16 have two flat parallel faces, more complex shapes may be advantageous and can be easily formed with standard machining techniques.

The slots 16 can be formed with any suitable diamond tool, such as a

commercial diamond saw blade. One example of a suitable cutting apparatus is a 3" to 4" resin bond wheel, manufactured by National Diamond Lab. Such a slotter is particularly effective when used with a blade having diamond-coated cutting surfaces, such as a 16 grit to 400 grit blade available from National Diamond Labs. During cutting of the slots 16, the slotter can be operated at speeds ranging from 5 rpm to 125,000 rpm. It has been discovered that a speed of approximately 4500 rpm is particularly effective. It is to be understood that the use of the specified cutting apparatus, while effective, is merely illustrative. It is contemplated that alternative cutting apparatus could be employed to achieve acceptable results. Examples of such apparatus include, but are not limited to, slotters using non-diamond blades, lasers, and abrasive fluid cutting devices.

Two distinct designs exist for attaching the leg 12 to the base 14. As illustrated in the elevational side view of FIG. 13 and the orthographic view of FIG. 14, the slotted leg 42 has a cross section exclusive of the slots 16 that extends to its ends 44 having a rounded wedge shape. Complementary blind rounded wedge shaped holes 46 are machined in the two opposed bases 14 to receive the rounded wedge shaped ends of the leg 42. This design offers the advantage of added rotational rigidity.

Alternatively, as illustrated in the elevational side view of FIG. 15 and the orthographic view of FIG. 16, at least one attachment structure 50 is machined on each of terminal ends 52 of a pegged leg 54. The attachment structure 50 is shown as a pair of opposed cylindrical pegs. The pegs are formed by machining the ends of the support member basic form 30. This machining can be performed with any suitable cutting mechanism. One example of a suitable cutting apparatus is a vertical or horizontal milling machine, or CNC machine, manufactured by companies such as NOVA, JET, or PRESTO. The attachment structure 50 is adapted and constructed to facilitate attachment of the leg 54 to the generally planar base 14 having a corresponding blind cylindrical mortise hole 56. Yet other forms of the attachment structure 50 are possible, for example, a blade shape with a corresponding trench shape in the base. It is further understood that the leg could be attached to the base in any suitable manner.

The finished leg 22 can be manufactured in any desired size. For example, the

illustrated leg can be formed from basic leg form having a width of approximately 0.475" (12mm) and a length of approximately 45" (114mm), with the wedge defining an angle of approximately 22° 60". The slots 16 in the illustrated embodiments have a depth of approximately 0.25" (6mm), and extend approximately 43" (109cm) along the length of the leg 22 although even longer lengths are possible. The cylindrical pegs 50 forming the attachment structure of FIG. 16 extend approximately 0.6" (15mm) from the ends of the leg 54, and have a diameter of approximately 0.4" (10mm).

Various techniques for securing the legs to the bases are illustrated in FIGS. 17 through 23. In each of these examples, as shown in FIG. 17, a first silicon member 60, here shown as the support member, is provided with an outwardly-extending attachment element or tenon 62. However, it is understood that the tenon 62 may be substituted by a continuation of the first silicon member 60, such as illustrated in FIG. 14. A second silicon member 64, here the base member, includes a mortise 66. The mortise 66 is adapted to at least partially enclose the tenon 62.

According to one embodiment, to fixedly secure the tenon 62 within the mortise 66, a first transverse bore 70 is drilled in the tenon 66, and a second transverse bore 72 is drilled in the portion of the second silicon member 64 adjacent to the mortise 66. The first and second transverse bores 70, 72 are sized to receive a locating pin 74 when they are coaxially aligned with one another.

The locating pin 74 can be secured in the first and second transverse bores 70, 72 in several ways. In the embodiment of FIG. 17, the locating pin 74 is slightly longer than the combined lengths of the first and second bores 70, 72. The locating pin 74 is inserted in the aligned bores 70, 72 such that a portion 76 of the locating pin 74 (shown in broken line) extends outwardly from an outer limit 78 of the second bore 74. Then, the outwardly extending portion 76 of the locating pin 74 is machined off flush with the outer limit 78 of the second bore 72.

An alternative securing technique is illustrated in FIG. 18. A locating pin 80 is has an outer diameter D_1 substantially equal to the inner diameter D_2 of the first and second bores 82, 84 in the tenon 62 and the portion of the second silicon member 64 adjacent to the mortise 66. In this example, the locating pin 80 is cryogenically frozen to approximately -100°C, thus causing the locating pin 80 to contract. Next, the

cooled locating pin 80 is inserted in the aligned bores 82, 84 while maintaining the bores at ambient temperature. Then, the locating pin 80 is caused to expand by allowing it to return to ambient temperature. The diameter of the locating pin 80 contracts approximately 0.001% when cryogenically frozen.

As an alternative to the techniques incorporating locating pins, energy can be applied to the tenon, the mortise, or both to fuse the tenon to the mortise.

One example of such a technique is shown in FIG. 19. In this example, an access bore 88 is drilled into the second silicon member 64 to reach the bottom of the mortise 66. Laser energy is applied through the access bore 88 to form a tack weld W between the tenon 62 and the mortise 66. It has been found that advantageous results are achieved with laser energy from a 250W CO_2 laser having a pulse width of 30ns and a pulse period of 0.001s, applied for 1 to 5 minutes. Any suitable source of laser energy may be employed, such as a CO_2 laser manufactured by Coherent.

Another assembly method is illustrated in the cross-sectional view of FIG. 20. In this example, the tenon 62 and the tenon 66 extend through the depth of the second silicon member are substantially coextensive. Laser energy can be applied to an area A_1 adjacent to the interface between the mortise 66 and tenon 66 to form a tack weld, which can extend around all or part of the interfacial area A_1. Any suitable source of laser energy may be employed.

In the further examples shown in FIGS. 21 and 22, the tenon 62 extends through the second silicon member 64 and includes a peripheral ridge 90 at its terminal end 92. The second silicon member 64 includes a peripheral bevel 94 surrounding the outer end of the mortise 66. Heat energy is applied to cause the peripheral ridge 90 of the first silicon member 60 to melt into the peripheral bevel 94 of the second silicon member 64, thus fusing the tenon 62 to the mortise 66. Any suitable heat source can be used to apply heat. It has been found that one heat source that can be used advantageously is heat generated from laser energy. Laser energy is used to heat the ridge 90 to above the melting point of silicon 1416°C, and preferably to a temperature of approximately 1450°C for approximately 3 minutes, or until the silicon melt has filled the peripheral bevel 94, as shown in FIG. 22.

Another securing technique is shown in FIG. 23. In this example, the step of fixedly securing the tenon 62 within the mortise 66 includes the step of applying

adhesive at an axially extending area A_2 between the tenon 62 and the mortise 66. In order to avoid contamination usually associated with the use of adhesives, a high-temperature, non-contaminating adhesive should be used.

The attachment elements illustrated in FIGS. 17 through 23 are shown as being generally cylindrical, with the attachment element receiving portions being formed as a cylindrical bores. It is to be understood, however, that these configurations are for exemplary purposes only, and that any suitable cooperating shapes may be chosen for the attachment elements and associated retaining portions.

The various described securing methods can be used not only for fabricating a wafer tower but also for other structures requiring the tight assembly of two or more silicon pieces.

To achieve the tower 10 illustrated in FIG. 1, one of the securing methods described above is applied between each of the legs 12 and the two bases 14; however, yet other securing methods are possible. Four legs 12 are preferred; three legs 12 are adequate; and, even two legs 12 might suffice. The mortises are bored into the two bases 14 preferably at equal angular positions over slightly more than 180°. The extra clearance afforded by the slots 16 then allow the blade of a robot to horizontally insert a wafer into the tower 10 by sliding it through the slots 16, preferably without engaging the sides of the slots 16 during insertion, and leave it stably supported on the bottom surfaces of the slots 16.

Although the bases 14 are illustrated in FIG. 1 as being continuous and symmetrically circular, they may have more complex though still generally circular. For example, they may includes external flats and internal apertures. Furthermore, although integral bases are preferred being formed out of a single crystal of silicon, a multi-part silicon base may be formed by securing multiple parts together. In this case, the use of virgin poly for the bases becomes more appropriate.

In the above described embodiments, slots were cut into wedge-shaped legs. However, the invention is not so limited. Other forms of legs and wafer supports are possible, such as silicon arms projecting from cylindrical or rectangular legs and supporting wafers on their distal ends.

The present invention enables the fabrication of monocrystalline silicon, polycrystalline silicon, or virgin polysilicon structural members for use in the

manufacture of semiconductor wafers and the like, and is applicable to any large scale and/or complex fixture or part used in the processing of silicon wafers. Components using structural members in accordance with the present invention eliminate deformation during high-temperature process applications. Since the source material is the same quality as the wafers material, particulate contamination and "crystal slip" inherent with known materials such as silicon carbide is virtually eliminated. Furthermore, there is no shadowing, since the source material provides a one-to-one duplication of the physical properties and critical constants of process wafers. Monosilicon fixtures and parts provide tolerances and expected service life unachievable with those made from commonly-used materials such as quartz or silicon carbide. The present invention enables the fabrication of silicon parts and fixtures that provide advantages as the industry moves to 300mm and larger wafer diameters.

Although the present invention has been described with reference to specific embodiments, those of skill in the art will recognize that changes may be made thereto without departing from the scope and spirit of the invention.

What is claimed is:

1. A silicon tower for supporting a plurality of wafers, comprising:

two bases composed of silicon; and

a first plurality of legs composed of virgin polysilicon secured at their two ends to said two bases and configured to removably support a plurality of wafers.

2. The tower as recited in Claim 1, wherein each of said legs have a plurality of slots cut into a first side thereof for supporting said plurality of wafers and allowing said wafers to be slidably inserted into said slots.

3. The tower as recited in Claim 2, wherein each of said legs is formed according to a cross-sectional leg shape including said first side which has a curved shape with a first radius, no portion of said leg shape having a radius of curvature less than said first radius.

4. The tower as recited in Claim 3, wherein said leg shape includes a second side opposed to said first side and having a curved shape with a second radius greater than said first radius.

5. The tower as recited in Claim 4, further comprising slots cut into said first side.

6. The tower as recited in Claim 3, wherein said leg shape includes a flat second side opposed to said first side.

7. The tower as recited in Claim 3, further comprising cylindrical holes formed in said bases and having have said leg shape to receive said legs.

8. The tower as recited in Claim 3, wherein said leg shape is non-circular and wherein each of said legs has formed on its two ends cylindrical pegs and further comprising cylindrical holes formed in said bases to receive said pegs.

9. The tower as recited in Claim 3, wherein said leg shape is a non-circular shape.

10. The tower as recited in Claim 9, further comprising holes having said non-circular shape formed in said bases to receive said legs.

11. The tower as recited in Claim 1, wherein each of said bases comprises virgin polysilicon.

12. The tower as recited in Claim 1, wherein each of said bases comprises Czochralski-grown silicon.

13. A silicon tower for supporting a plurality of wafers, comprising:

two bases, each comprising a plurality of parts secured together and composed of virgin poly; and

a first plurality of legs comprising virgin polysilicon secured at their two ends to said two bases and configured to removably support a plurality of wafers.

14. The silicon tower as recited in Claim 13, wherein each of said legs includes a plurality of slots cut into a side thereof for supporting said plurality of wafers and allowing said wafers to be slidably inserted into said slots.

15. A support member for wafer processing fixtures, comprising:

an elongate silicon body portion having a cross-sectional body shape including an arcuate front surface with a first radius of curvature and a back surface opposed to said front surface and being either flat or having a second radius of curvature greater than said first radius of curvature, no other portion of said body shape having a radius of curvature less than said first radius of curvature; and

a plurality of mutually parallel wafer-retaining slots formed in the front surface of the body portion.

16. The support member according to Claim 15, wherein said back surface is curved and a ratio of said second radius to said first radius is at least 3.

17. The support member according to Claim 15, wherein said back surface is flat.

18. The support member according to Claim 15, wherein said silicon member comprises virgin poly.

19. The support member according to Claim 15, wherein said silicon member comprises monocrystalline silicon.

20. A method of securing a first silicon member to a second silicon member to form at least a part of a silicon wafer processing fixture, the method comprising the following steps:

providing a first silicon member with an outwardly extending portion;

providing a second silicon member with an attachment element receiving portion adapted to at least partially enclose the outwardly extending portion;

placing the outwardly extending portion into the attachment element receiving portion; and

fixedly securing the outwardly extending portion element within the attachment element receiving portion, wherein the securing step includes applying energy to at least one of the outwardly extending portion and the attachment element receiving portion to fuse the outwardly extending portion to the attachment element receiving portion.

21. The method of Claim 20, wherein the step of applying energy comprises applying laser energy.

22. The method of Claim 20, wherein said attachment element receiving

portion includes a bevel around a bore to receive said outwardly extending portion.

23. The method of Claim 20, wherein said outwardly extending portion includes a portion extending beyond said attachment element receiving portion adapted to be melted into and fused with said attachment receiving portion when applied with said energy.

24. The method according to Claim 20, wherein the first and second silicon members are formed from a material selected from a group consisting of monocrystalline Czochralski-grown silicon, polycrystalline Czochralski-grown silicon, and virgin polysilicon.

25. The method according to Claim 24, wherein at least one of said first and second silicon members comprises virgin polysilicon.

26. The method according to Claim 20, wherein the step of applying energy comprises applying laser radiation to melt the outwardly extending element to a temperature above 1416°C.

27. The method according to Claim 20, wherein the outwardly extending portion of the first silicon member is a generally cylindrical outwardly-extending attachment element, and wherein said attachment element receiving portion is formed with a cylindrical bore in the second silicon member for accommodating said outwardly extending portion..

28. The method according to Claim 20, wherein said first silicon member has a non-circular shape and said outwardly extending portion and said attachment receiving portion has said non-circular shape.

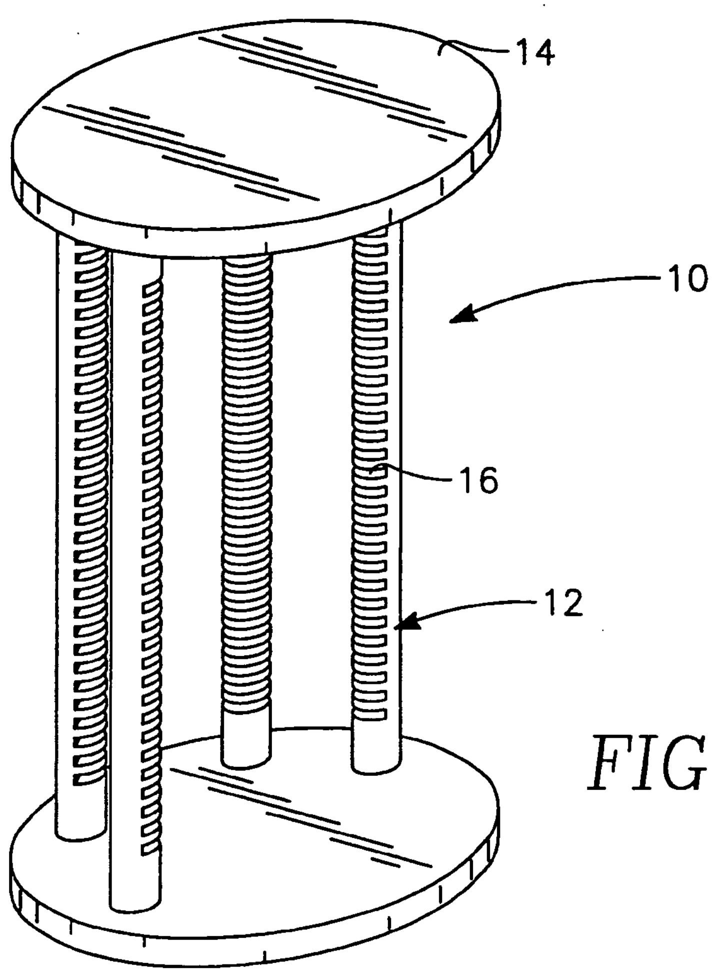

FIG. 1

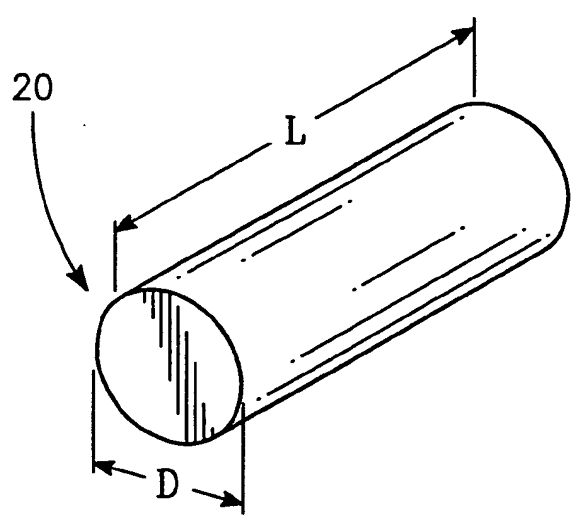

FIG. 2

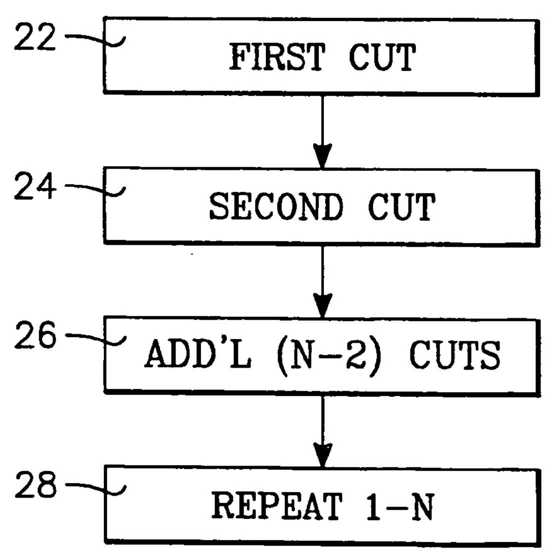

FIG. 3

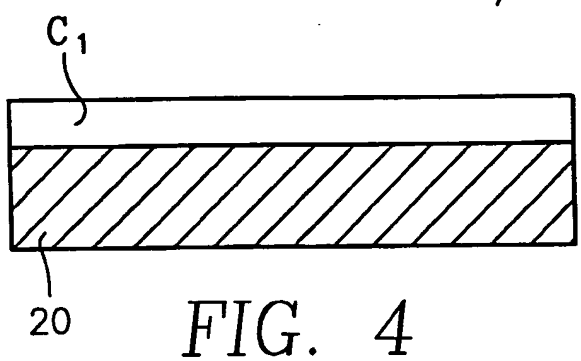

FIG. 4

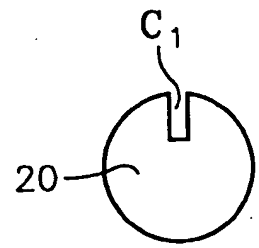

FIG. 5

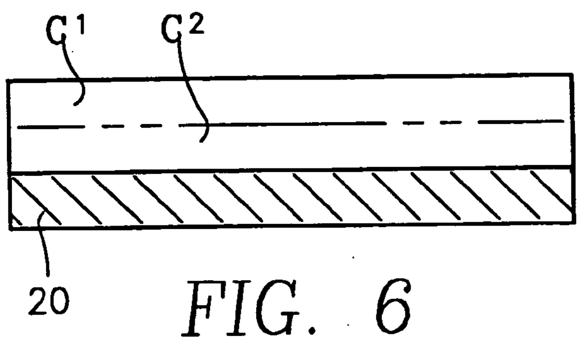

FIG. 6

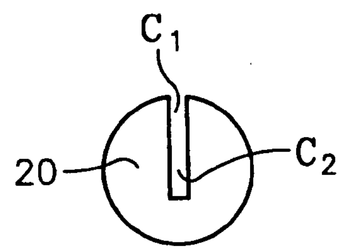

FIG. 7

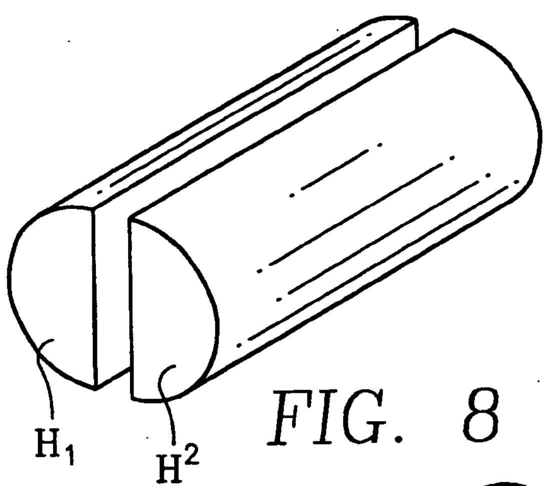

FIG. 8

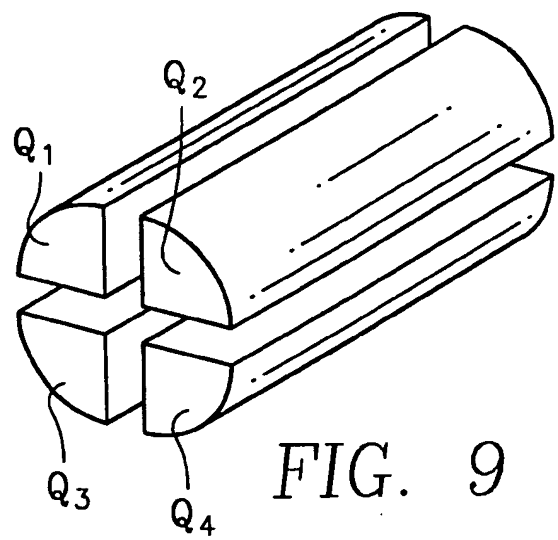

FIG. 9

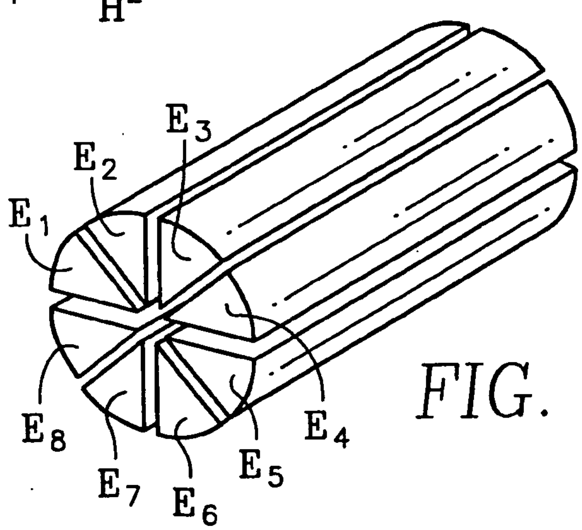

FIG. 10

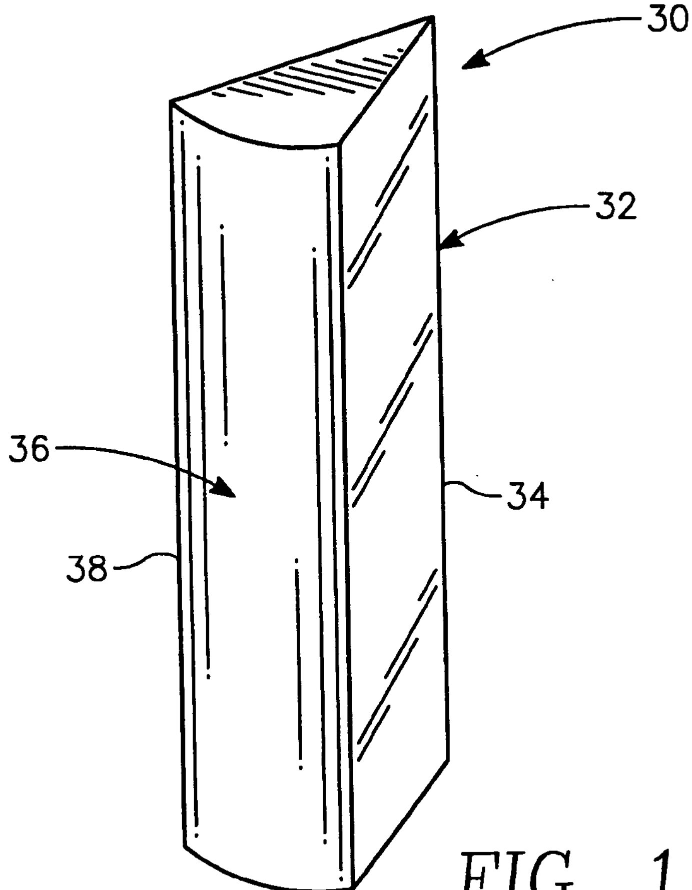

FIG. 11

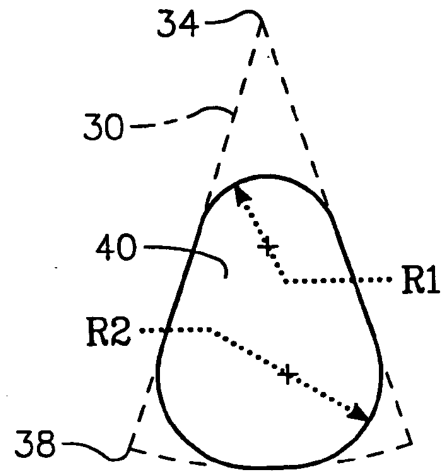

FIG. 12

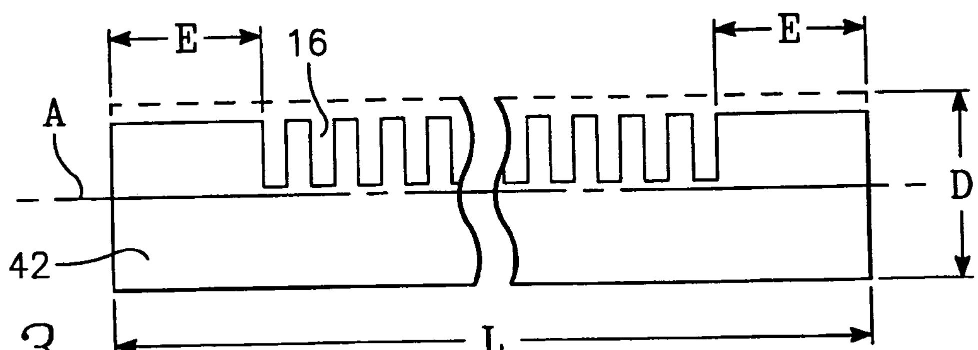

FIG. 13

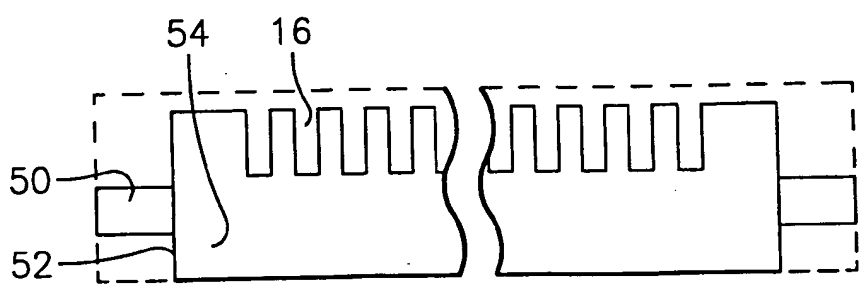

FIG. 15

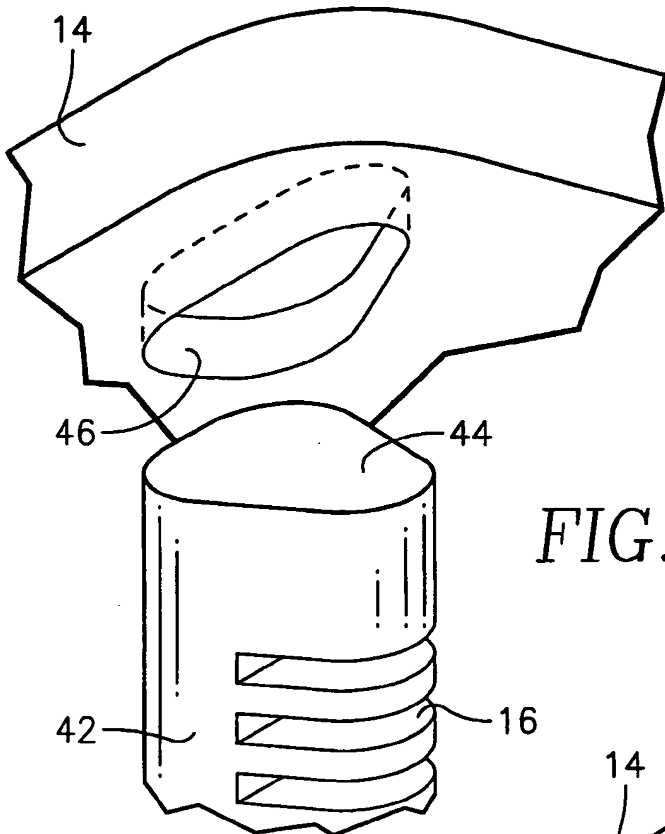

FIG. 14

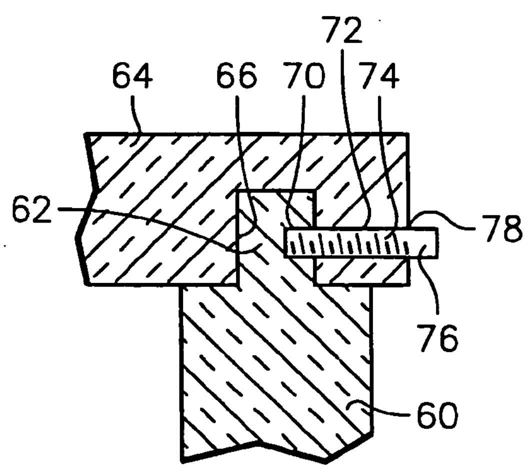

FIG. 17

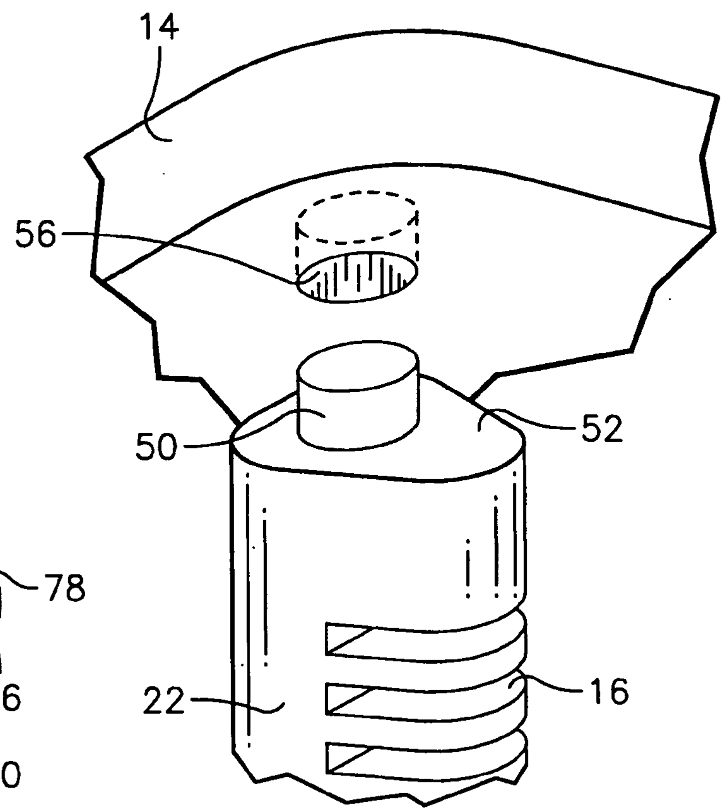

FIG. 16

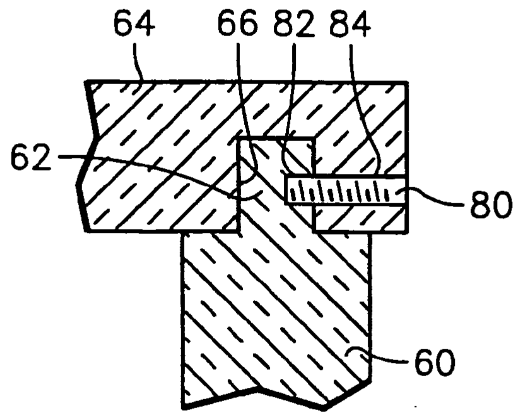

FIG. 18

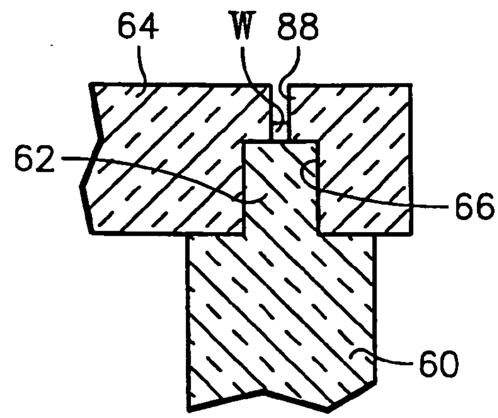

FIG. 19

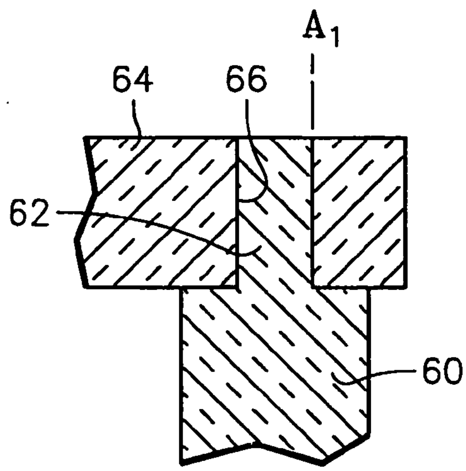

FIG. 20

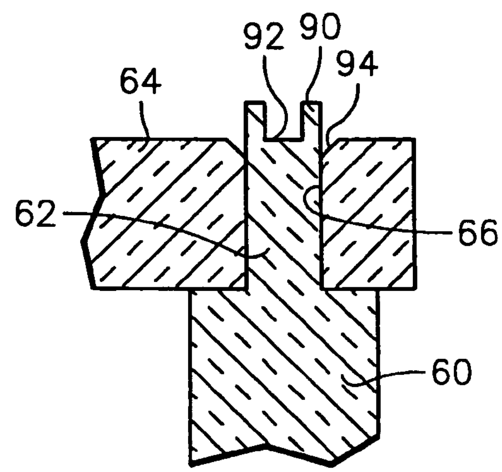

FIG. 21

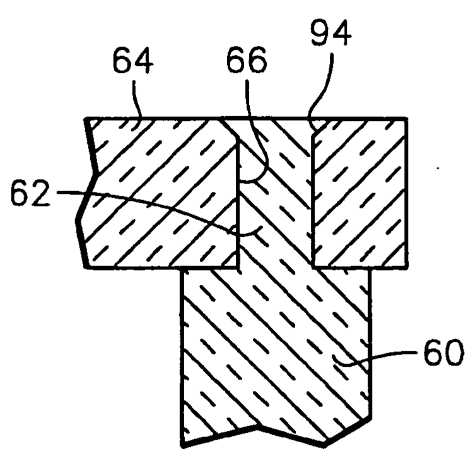

FIG. 22

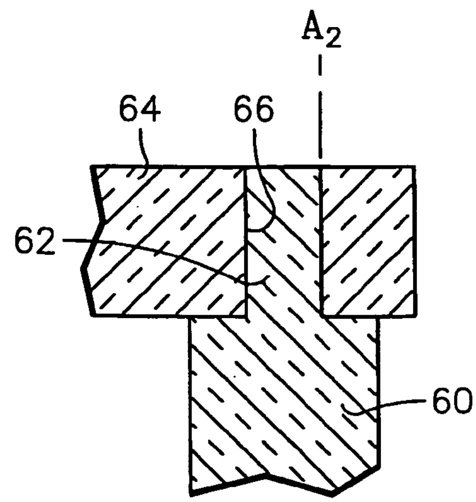

FIG. 23

INTERNATIONAL SEARCH REPORT

Int nal Application No
PCT/US 00/09362

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01L21/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 586 880 A (OHSAWA TETSU) 24 December 1996 (1996-12-24) claims 1,2	1,2,11, 13,14
A		12,15, 18,20, 24,25

X	US 5 492 229 A (TANAKA TAKASHI ET AL) 20 February 1996 (1996-02-20) cited in the application	1-3, 11-14
Y	column 7, line 25 -column 8, line 8	7,8,15, 18-27

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
9 August 2000	22/08/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Hamdani, F

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INTERNATIONAL SEARCH REPORT

Int nal Application No
PCT/US 00/09362

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	US 4 914 269 A (KINSMAN LARRY D ET AL) 3 April 1990 (1990-04-03) abstract	21,26
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E	WO 00 21119 A (WINGO LARRY S ;UNION OIL CO (US)) 13 April 2000 (2000-04-13) page 10, line 6 - line 14 figures	1,2, 11-14

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Information on patent family members

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